'*Power under pressure*' – defibrillation during hyperbaric oxygen therapy: a scoping review

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Abstract
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Introduction: Although defibrillation is the standard treatment for cardiac arrest with shockable rhythms, its safety during hyperbaric oxygen therapy (HBOT) remains uncertain, as the oxygen-enriched atmosphere and increased ambient pressure could, in case of sparking, increase fire and explosion risk. As established guidelines are lacking, this scoping review synthesizes the current knowledge, addressing the unique challenges that arise in this special environment.
Methods: A systematic literature search was conducted in CINAHL, Cochrane Library, EMBASE and PubMed. Two authors independently screened titles and abstracts, with a third author resolving discrepancies. Duplicate records were removed after initial screening. Full-text screening was also performed independently by two authors. Manual data extraction focused on actual defibrillation during HBOT, including outcomes, safety concerns, recommendations and further helpful information.
Results: The search initially identified 10,348 publications, ten of which were included. Screening of reference lists yielded another 23 publications, resulting in 33 finally included publications. Of these, four publications presented five patient cases of actual defibrillation during HBOT, while the remaining publications provided additional information on the topic.
Conclusions: Findings highlight a lack of standardised guidelines and limited empirical data, necessitating cautious consideration of defibrillation during HBOT. Safety protocols, including oxygen level and equipment specifications, vary between monoplace and multiplace hyperbaric chambers, influencing the feasibility of in-chamber defibrillation. There is strong consensus that defibrillation is strictly contraindicated inside monoplace chambers, while in multiplace chambers, risks and benefits must be assessed individually. While defibrillation during HBOT is rare, ensuring its safety remains of paramount importance. Future research should focus on refining safety protocols and establishing guidelines to optimise patient outcomes during HBOT-associated emergencies.

Introduction

Originally developed for diving medicine, hyperbaric oxygen therapy (HBOT) is now used for a wide range of conditions, though the strength of evidence supporting these varies considerably.[1] Monoplace and multiplace hyperbaric chambers present distinct treatment environments with certain technical and structural requirements, each having specific and stringent safety measures, ensuring safety and efficacy.[2,3]

Given the critical conditions treated, managing life-threatening emergencies is crucial. Defibrillation is the primary treatment for cardiac arrest with shockable rhythms. Although chest compressions maintain blood flow, they cannot restore a normal heart rhythm.[4] Early

defibrillation significantly improves survival rates, while any delay decreases likelihood of hospital discharge in out-of-hospital cardiac arrest by eight to ten percent per minute.[5] Ensuring timely access to defibrillation is one of the most critical interventions improving patient outcomes. So far, only two defibrillators are manufacturer approved for use during HBOT (Corpuls3 HBO and Haux Hyperbaric Defibrillator),[2,6,7] while a further two have been tested.[7,8] Defibrillators certified or tested for use under hyperbaric conditions are shown in Table 1.

Nevertheless, hyperbaric defibrillation carries risks, most notably, potential for chamber fires triggered by sparks, which are particularly hazardous in increased ambient pressure and potentially oxygen-enriched chamber air.[9] Evidence on the appropriate course of action in such situations is limited. The current European Resuscitation Council guideline "*Cardiac arrest in special circumstances*" provides no recommendations for resuscitation during HBOT, unlike initial guidelines for space or underwater resuscitation.[10,11]

To address this issue, Schmitz et al., conducted a comprehensive literature review in 2023 examining cardiopulmonary resuscitation within the context of HBOT.[12] Notably, two present authors (SN, TS) were part of the working group. Building on this foundation, the current scoping review was specifically directed at defibrillation – a vital component of cardiopulmonary resuscitation, that was not explicitly captured by the original search string. Consequently, it was refined to uncover unrecognised publications, enabling a more detailed analysis of defibrillation during HBOT.

This scoping review aims to compile the available evidence, providing a deeper investigation into the considerations and evaluating whether defibrillation under increased pressure could be performed safely, following a risk-benefit analysis. Thus, contributing to the development of future guidelines on safety and feasibility of hyperbaric defibrillation.

Given the added complexity of defibrillation in other hyperbaric environments e.g., during saturation diving,[13–16] these contexts are not included in this review.

Methods

This review is part of the doctoral thesis of author SN, for which ethical approval was granted by the Ethics Committee of Witten-Herdecke University (No. S-261/2022). This scoping review predominantly followed the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) extension for scoping reviews,[17] other than the deviations described in the text. It was conducted without a previously registered protocol and received no financial support or external funding.

Table 1
Defibrillators manufacturer approved or tested for use under hyperbaric conditions; HBOT – hyperbaric oxygen therapy

Company	Website	Device	Specific features
Corpuls	https://corpuls.world	Corpuls3 HBO	HBOT-certified by manufacturer[2,6,7]
Haux	https://hauxlifesupport.de	Hyperbaric defibrillator	HBOT-certified by manufacturer[2]
Stryker (formerly Physio Control)	https://www.stryker.com	Lifepak 1000	Not HBOT-certified by manufacturer, but has been tested successfully under hyperbaric conditions[7]
Zoll	https://www.zoll.com	AED Plus	Not HBOT-certified by manufacturer. Testing under hyperbaric heliox conditions revealed results that cast doubt on the unit's performance reliability after pressurisation[8]

SEARCH STRATEGY

Search string used in databases

A comprehensive literature review was conducted adapting the search string used by Schmitz et al.,[12] with regard to defibrillation. The literature search was performed in CINAHL, Cochrane Library, EMBASE and PubMed up until 1 October 2024. Details on the search string, used search modes and filters can be found in the *Appendix.

Additional sources

Following screening of publications identified through the database search, reference lists of those ultimately included in the review were screened.

INCLUSION CRITERIA

All publications explicitly describing defibrillation during HBOT, encompassing both patient cases or general information on defibrillation during HBOT, were included. Publications were included regardless of the type of article or year of publication.

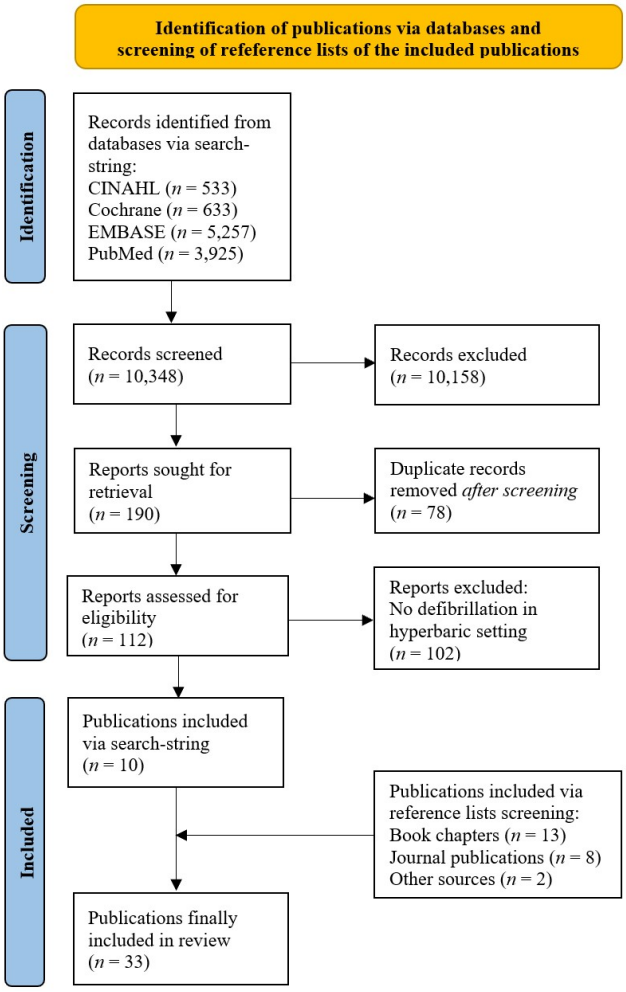
EXCLUSION CRITERIA

Publications only providing indirect hints that could relate to hyperbaric defibrillation without concretely addressing the topic were excluded. Furthermore, we excluded articles dealing with hyperbaric environments other than HBOT (such as saturation diving as mentioned above). Additionally, articles written in languages other than English or German and animal studies were excluded.

EVALUATION AND DATA INTERPRETATION

The screening process was conducted by two authors independently (SN, TS), commencing with title, followed by extended title and abstract screening. In instances of discordance, a third author (DG) was consulted as a referee. Duplicate records were removed after initial screening. All records deemed possibly relevant were sought for retrieval. Full-text screening was conducted independently by two authors (SN, TS), who also made the final decision on which publications to include in the review. All relevant data from the included publications were extracted manually, focusing on patient cases of actual defibrillation during HBOT and their reported outcomes, safety concerns and recommendations as well as other helpful information on the topic (SN, TS, DG, CB). This information was then interpreted descriptively in form of a narrative evidence synthesis (SN, TS). The most important contents were then summarized in a table to provide a clear and structured overview of the key information (SN, TS). Screening of the reference lists of the publications included in this review was carried out subsequently (SN, TS). In case of newly found articles deemed relevant, the screening process started from the beginning as described above.

Figure 1
Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) flowchart for the present review



Results

A total of 10,348 publications were identified through our primary search strategy via databases using the adapted search string. After the multi-stage screening process, 112 publications were fully reviewed, and 10 publications[2,6,7,9,12,18–22] were initially included in this review. Screening of reference lists of the included publications led to the addition of 23,[3,23–44] bringing the total number of publications finally included in this scoping review to 33.

This process is presented in a PRISMA flowchart[45] in Figure 1.

DEFIBRILLATION DURING HBOT

Of the 33 identified publications, four include case reports

***Footnote:** The Appendix is available to download from https://www.dhmjournal.com/index.php/journals?id=376

describing a total of five cases of actual defibrillation or cardioversion during HBOT,[19,20,24,40] as reported in the end of this section. The remaining 29 provide general information on the topic. These results are summarised in Table 2.

Of the additional 29 publications identified as thematically appropriate, only two dealt exclusively with hyperbaric defibrillation.[9,34] A further three were devoted to defibrillation as part of recommendations for cardiopulmonary resuscitation in the hyperbaric environment.[6,12,21] Further information can be found in 14 other publications, which mainly deal with HBOT of critical care, intensive care or emergency patients.[2,3,18,22,25–28,36,37,39,41,42,44] Six publications dealt with equipment and procedures that can be carried out in hyperbaric chambers.[7,23,31–33,35] The remaining four focused on safety guidelines,[43] general principles of HBOT and possible complications,[29,30] or its use in treating specific conditions.[38]

Within the aforementioned additional 29 publications, the review by Schmitz et al., identified 22 cases of cardiopulmonary resuscitation performed during HBOT,[12] including a defibrillation case that is consistent with one identified in our search.[12,24] Over a 20-year period involving more than 120,000 HBOT cases, Kot reported encountering a small number of fatal cases where defibrillation was indicated. Unfortunately, the source does not provide information on whether these were merely indicated or actually performed.[7]

TYPE OF DEFIBRILLATOR AND LOCATION DURING HBOT

Six publications provide information on the defibrillator itself.[2,3,9,22,27,34] Only a few are manufacturer approved or have been reported reliable for use under hyperbaric conditions.[2,6,7,22]

Various authors mention that a stand-alone battery-powered defibrillator can be used inside a multiplace chamber,[2,6,7,26] which should be stored outside and brought inside via a lock in an emergency.[6] Others recommend storing and operating the defibrillator from outside, and connecting to the patient via cables through the chamber wall.[2,3,7,9,12,20,22,28,30–35,44]

POTENTIAL RISKS ASSOCIATED WITH HYPERBARIC DEFIBRILLATION

The increased risk of fire, attributed to the oxygen-enriched atmosphere and high partial pressure, was identified as the greatest concern when performing defibrillation during HBOT.[3,6,7,9,12,18,20,21,23,25–29,31–34,36–42,44] In addition to a possible risk of explosion,[3,6,9,36,37] there are also general safety concerns.[2,22] Potential power transmission to bystanders during shock application is also described.[9,12,21] Defibrillator malfunction under increased pressure and possible operating errors due to nitrogen narcosis in chamber staff might also pose a risk.[9,12,34,37]

SAFETY PRECAUTIONS AND RECOMMENDATIONS FOR PERFORMING HYPERBARIC DEFIBRILLATION

Defibrillation inside monoplace chambers is contraindicated due to the high fire risk associated with the 100% oxygen environment.[7,27,28,30–32,34–37,39–44] Some authors state that defibrillation is possible in multiplace chambers if strict safety measures are fulfilled,[2,6,7,9,12,20,22,23,26–28,30–35,42,44] while others recommend that the patient should first be decompressed on an emergent basis and defibrillated outside in a normobaric setting.[2,3,7,9,18,21,25,29,37,38] The differences between considerations for defibrillation in monoplace and multiplace chambers are shown in Table 3.

PATIENT OUTCOMES

Some authors mention that hyperoxygenation during HBOT may have a protective effect, potentially extending the time a patient can tolerate cardiac arrest and thereby giving healthcare providers a certain time buffer to intervene.[2,7,9,25,28–32,39–41]

Of the three patient cases of actual defibrillation during HBOT in a multiplace chamber, identified in our review, two initially survived.[19,20,24] In both, the defibrillation and cardioversion followed emergency decompression of the monoplace chamber, and the procedure appeared to be successful.[40] No further information was given on the long-term outcome.[19,20,24,40]

CASE REPORTS

Wolf et al., described a 69-year-old woman treated in a monoplace chamber due to her non-healing foot ulcer. She suffered pulmonary barotrauma with air embolism to the brain and was transferred to a multiplace chamber, where she was recompressed to 284 kPa (60 feet, 18.3 metres sea water equivalent) and received 100% oxygen. During decompression she suffered from multiple episodes of ventricular tachycardia and hypotension and was therefore defibrillated and received antiarrhythmic drugs and pressor agents. She later died in the intensive care unit.[24]

Murphy et al., described a 17-year-old female with severe carbon monoxide intoxication. When HBOT began, the patient was comatose. Five minutes after starting HBOT, she suffered pulseless ventricular tachycardia. She was immediately cardioverted by the intensive care nurse present in the chamber, successfully converting into sinus tachycardia.[19]

The third case report described a successful defibrillation performed at 265 kPa in a multiplace chamber without any safety issues. Unfortunately, very little information on the medical history is provided.[20]

Table 2

Results of the literature search - each row represents one or more studies by an author or authorship group. ASAP – as soon as possible; atm abs – atmospheres absolute; CA – cardiac arrest; CO – carbon monoxide; CPR – cardiopulmonary resuscitation; DCS – decompression sickness; ETI – endotracheal intubation; ft – feet; HBOT – hyperbaric oxygen therapy; ICU – intensive care unit; i.v. – intravenous; msw – metres of sea water; MoPC – monoplace hyperbaric chamber; MuPC – multiplace hyperbaric chamber; O_2 – oxygen; PVT – pulseless ventricular tachycardia; VF – ventricular fibrillation; VT – ventricular tachycardia

Reference	Commentary / recommendations
6	Fire/explosion hazard; if applicable, precordial punch Battery-operated defibrillator outside chamber; CPR, then emergency lock-in; reduce energy for first shock to 150 J
28	MuPC: special precautions; possibly operate from outside with cables through chamber wall MoPC: never inside; rapid but controlled decompression (2–4 minutes); don't defibrillate directly after opening, oxygen spilling from inside for 10-30 seconds; remove patient, defibrillate as far as away as practical
23	Fire hazard higher in MoPC than in MuPC Not standard, but still possible if safety precautions are observed
29	Risk of fire; defibrillator placed outside; overall questionable safest approach: decompress while CPR, defibrillate outside; super-oxygenated, short time delay should be no risk
30	MuPC: possible with certain precautions; otherwise emergency decompression; note decompression of inside tender MoPC: remove patient (< 1 minute); '*grace period*' of several minutes; oxygen will diffuse to floor, tests showed no rise at level of patients chest outside chamber; dissipated within 30 to 40 seconds
7, 31, 32	Rarely needed;[7] dangerous, risk of fire caused by electrical discharges and voltaic arc between paddles[7,31,32] MoPC: absolutely contraindicated;[7,31,32] emergency decompression, but could cause complications if unresponsive[32] MuPC: can be performed safely with several precautions; compressed with air, oxygen below 21.5%; large surface adhesive plates, use gel, cables of wide diameter and low resistance, defibrillator outside; three persons needed: attendant inside, external defibrillator's operator, chamber operator[7,31,32] if impossible, defibrillate outside after emergency surfacing; preoxygenation might buffer for a few more minutes[7,31,32] two modern, stand-alone defibrillator approved for hyperbaric use, makes it easier than ever, but still risk of fire[7]
26	MuPC possible with battery-operated defibrillator MoPC: Use of any technical devices due to O_2 enrichment and fire hazard impossible
33	High risk of fire Defibrillator outside chamber with connection inside, use large adhesive plates, operated from outside doctor
34	MoPC: contraindicated; MuPC: hazardous, fire, implosion, operator error, minimised by leaving monitor outside Test of Life Pak 6S defibrillator with R-2 defibrillator adapter; self-adhering pads anteriorly and posteriorly, reducing risk of arching; average power loss of 9%, but within acceptable limits by manufacturer
3	Risk of explosion '*Triangle of fire*' Safe defibrillation: attach self-adhesive pads prior to HBOT, defibrillator outside Advantage of defibrillation during HBOT not proven
2	Battery-operated; alternatively, outside chamber with cable connection through wall Shockable rhythm unlikely; O_2-reserve, therefore decompression first
17	Possible in MuPC, device outside chamber; risk of fire; removal of flammable material; if no pads, consider gel Case report: successful defibrillation in MuPC (2.7 atm abs/ 265 kPa) without complications

Table 2 continued.

35	MuPC: Fire risk if sparking or combustible materials near paddles; use low-resistivity conductive gel or preapplied conductive disposable pads; defibrillator outside with connection inside MoPC: cannot be safely performed in chamber compressed with oxygen
19	· Patient with severe CO intoxication requiring resuscitation; comatose at start of HBOT · Suffered PVT 5 minutes after onset of HBOT, immediately cardioverted in chamber
18, 36, 37	· MoPC: impossible due to prevailing 100% oxygen atmosphere;[36,37] emergency decompression without DCS risk; totally decompress, remove patient completely, oxygen outflow increases fire and explosion risk[37] · MuPC: CPR increases nitrogen uptake for inside staff, DCS risk; decompress slowly with attendants breathing O_2 at 1.9 atm abs until normobaric;[18,36,37] defibrillation possible, if chamber oxygen not elevated; yet critical due to fire and explosion risk[36,37] as well as equipment malfunction;[37] oxygen contamination seems to be inevitable during CPR[37] · MuPC less fire hazard than MoPC; use specially equipped resuscitation bag to prevent oxygen contamination[37] · If necessary: electrodes with largest contact surface, use gel and adhesive pads; defibrillator outside chamber; ensure fire extinguishing equipment available inside;[36,37] strongly recommended to avoid defibrillation inside MuPC; safest method: decompress while CPR, defibrillate in unpressurised chamber with door wide open[18,37]
22	· Defibrillation in chamber dangerous; only few devices approved for HBOT · Safest shock delivery: controlled outside the chamber, cable through the chamber wall, adhesive pads; reduce risk of flammability: chamber air like ambient air
9	· Risk of arrhythmias during HBOT low; HBOT appears to prolong tolerance for CA · Risk of fire, implosion, operating errors, malfunction; therefore, defibrillator outside · Reduce risk of shock transmission: grounding, insulating shoes, adhesive electrodes, biphasic defibrillation · Consider medical therapy for VF if monitoring, central i.v. access, ETI; depending on indication, emergency decompression could cause CA to worsen; overall, emergency decompression and normobaric defibrillation
44	· Fire hazard due to electrical sparking in chamber · MuPC: Area around paddle has to be free from flammables; use gel; defibrillator stored and operated from outside · MoPC: do not defibrillate in chamber filled with pure oxygen
12	· Risk of fire biggest concern + poses further risks (e.g., risk of current transmission) · Store defibrillator outside; use biphasic device with chest panels connected to patient with cables through chamber · If defibrillation necessary oxygen concentration shouldn't exceed 21.5% · Avoid current transmission: earthing of chamber, grounding footwear, sufficient distance from patient
38	· Risk of fire due to elevated oxygen level of chamber air; staff performing CPR increased nitrogen uptake · Avoid defibrillation inside; slowly decompress with staff breathing oxygen from 9 msw until normobaric · Only use specialised resuscitation bags to avoid oxygen contamination of the chamber to reduce fire risk
43	· MoPC: in chambers compressed with 100% oxygen, defibrillation at least 6–8 ft away from open door of recently decompressed chamber

Table 2 continued.

27, 39–42	. MoPC: patient supersaturated; O_2 pours from chamber into room, move stretcher away to keep distance; remove clothing due to increased fire risk; brain and heart presumably high O_2, taking a few seconds acceptable[39-41] . Measured oxygen levels after emergency decompression; oxygen falls to floor, dissipates within 30 seconds, does not remain elevated at patient level, doesn't rise in room;[39,40] . MoPC: under no circumstances in pure oxygen atmosphere of chamber; defibrillate outside[39] . Case reports: successfully defibrillated one patient and cardioverted another who were rapidly removed from MoPC for dysrhythmias; a few seconds elapsed following extraction before defibrillation; both treated while on the gurney attached to the MoPC; no evidence of spark or fire;[40] only two cases in more than 10 years[41] . MuPC: Defibrillation and cardioversion can be performed, if no excess oxygen build-up[27,42] . MoPC: decompress first, get patient out of chamber; during decompression, switch to air; if not possible, wait at least 40 seconds; remove clothing as it will be oxygen enriched and thus increase the risk of fire[27,42]
25	. Decompression ASAP: defibrillation when normobaric as there is a risk of fire . Hyperoxia may prevent tissue hypoxia during CA and may improve survival
24	. Case report: 69-year-old woman, non-healing foot ulcer, about 20 HBOTs in MoPC; suffered pulmonary barotrauma with air embolism; transferred in MuPC; recompression to 60 ft with 100% O_2; during decompression multiple episodes VT + hypotension; defibrillation, antiarrhythmics, pressor agents in chamber; died in ICU
21	. Defibrillation may cause dangerous sparks, risk of fire due to arcing . Decompression and defibrillation in normobaric atmosphere

The fourth report described the successful defibrillation of one patient and cardioversion of another, both of whom were rapidly removed from the monoplace chamber due to dysrhythmias. Defibrillation was conducted after a few seconds elapsed following extraction, while the patients were still on the gurney connected to the chamber. Notably, no evidence of sparks or fire were observed during either intervention.[40]

Discussion

To the best of our knowledge, this is the first review since 1999[9] to specifically address defibrillation in the hyperbaric setting – a potentially life-saving but high-risk procedure. With the increasing number of critically ill patients undergoing HBOT, a re-examination of defibrillation practices is both timely and necessary.

DEFIBRILLATION DURING HBOT

Defibrillation during HBOT itself is an exceptionally rare event with very few documented cases.[7,12,19,20,24,40] This is also reflected in our results, where we were only able to identify five cases of defibrillation or cardioversion.[19,20,24,40] Unfortunately, the case reports provide only limited insight, making it difficult to draw reliable conclusions from them. It must be noted that the case reports by Wolf et al.,[24] and Murphy et al.,[19] contain inaccuracies in terminology used for electrical therapy. Although the terms used in both cases are incorrect,[19,24] it is important to note that both defibrillation and cardioversion rely on electrical energy, albeit with differences in shock delivery and intensity.[46]

The life-threatening conditions of these patients underscore the urgent need for comprehensive guidelines on defibrillation during HBOT to optimise patient outcomes.

TYPE OF DEFIBRILLATOR AND LOCATION DURING HBOT

There are only a few manufacturer approved or tested defibrillators for hyperbaric use,[3,7–9,22] and reliability under pressure may vary.[9,22] Due to the niche market and financial constraints, many manufacturers do not pursue hyperbaric approval, shifting responsibility for use of uncertified devices to the physician.[3,44] Others may also be suitable, but remain unverified due to absence of testing. It is important to distinguish between the defibrillator's ability to safely withstand pressurisation and depressurisation, and its use when connected via a penetrator outside the hyperbaric chamber. Depending on the defibrillator itself, there is risk of possible malfunction due to the increased ambient pressure.[9,12,37] However, there are data showing that the defibrillator as a device *per se* is safe up to 304 kPa chamber pressure.[3] Some portable, battery-operated and CE-certified defibrillators have been available for several years.[2,6,26] Alternatively, a defibrillator may also be stored and operated

Table 3
Differences between monoplace and multiplace hyperbaric chambers regarding defibrillation; CA – cardiac arrest; HBOT – hyperbaric oxygen therapy; O_2 – oxygen

Parameter	Monoplace chamber	Multiplace chamber
Capacity (patients)	One	4–12
Patient accessible (e.g., through lock)	No	Yes
O_2 fraction inside chamber	100%	Should not exceed 21.5%
Defibrillator instantly accessible	No	Yes
Defibrillation possible inside chamber and procedure for defibrillatable CA	No, emergency decompression and normobaric defibrillation	Yes, feasible but only with strict safety precautions

from outside, connected to the patient via cables through the chamber wall, under the assumption that this arrangement reduces fire risk by minimising device-induced sparking and thereby lowering overall risk.[2,3,7,9,12,20,22,28,30–35,44] Wright et al.,[21] state that defibrillators are equipped with large capacitors and small brushed motors, known to discharge and spark. While older or specialised models may have used motor-driven components, the main concern remains capacitor discharge and potential arcing between paddles. However, technological advances, including the shift from paddles to adhesive pads, have significantly reduced risk of spark-induced fires. Jacobs et al. noted that no spark-related fires have been reported since these improvements.[47]

Direct patient access is impossible inside a monoplace chamber, making urgent decompression mandatory in emergencies.[27] In the prevailing 100% oxygen environment, defibrillation is contraindicated due to fire hazards. The victim must first be brought outside to a normobaric atmosphere.[7,27,28,30–32,34–37,39–44] In contrast, multiplace chambers might allow defibrillation under rigorous safety measures.[2,6,7,9,12,20,22,23,26–28,30–35,42,44] Direct hands-on treatment by specialised in-chamber staff is possible.[26,27] Recent data conclude that defibrillation could be safe if stringent safety precautions are observed.[12]

Millar explicitly states that most centers do not locate a defibrillator in the multiplace chamber itself, since cardiac arrest caused by a shockable rhythm is unlikely during HBOT and the patient usually has sufficient oxygen reserves to first perform complete decompression.[2] This contrasting approach of avoiding a possibly hazardous defibrillation by decompressing and subsequent normobaric defibrillation is also advised by other authors.[2,3,7,9,18,21,25,29,37,38] So far, our data does not support any standardisation on whether defibrillation is performed inside or outside the multiplace chamber. However, when the decision is made to perform in-chamber defibrillation, it is essential to prioritise devices that are either manufacturer approved or specifically tested for hyperbaric use, as this ensures adherence to fundamental safety standards.

POTENTIAL RISKS ASSOCIATED WITH HYPERBARIC DEFIBRILLATION

In addition to general safety concerns[2,22] and the potential explosion risk,[3,6,9,36,37] the risk of fire is regarded as the primary safety concern associated with defibrillation during HBOT.[3,6,7,9,12,18,20,21,23,25–29,31–34,36–42,44] Risks increase with each use of electrical, high voltage equipment, which may contribute to the '*triangle of fire*'. This includes increased oxygen concentrations, the presence of flammable substances and possible ignition sources.[3] Risks derive from sparking and voltaic arcing possibly occurring between the paddles, and oxygen that may originate from the respiratory system.[12,21,34,35,44] In monoplace chambers the overall fire risk is higher than in multiplace.[23,37]

Many authors derive their conclusions about the fire risk of hyperbaric defibrillation from fire incidents reported in earlier literature such as the publication by Simini[48] and the review from Sheffield and Desaultels.[49] Simini described the devastating consequences of the multiplace chamber fire in Milan in 1997, which resulted in eleven deaths.[48] Sheffield and Desautels analysed 25 chamber fires from 1923 to 1996 resulting in 60 deaths. The analysis showed, that oxygen concentration inside the chamber appears to have a major influence on probability of survival.[49] Although none of these incidents was caused by defibrillation, they demonstrate the catastrophic consequences a fire or explosion in a pressure chamber may have.[48,49]

Operating errors resulting from nitrogen narcosis in chamber personnel may represent a potential safety risk.[9,12,34] Defibrillator malfunction under increased ambient pressure, together with limited availability of approved devices, seem to present a safety risk to the patient and all individuals present.[9,12,22,37] Bystanders might be at risk of current transmission due to shock delivery.[9,12,21] If the decision is made to perform defibrillation inside the pressure chamber, it is of utmost importance to minimise the associated risks in order to perform defibrillation as safely as possible.

It is crucial to highlight that the majority of concerns regarding fire risk associated with defibrillation during HBOT are not based on direct empirical evidence, but rather inferred from real-life fire incidents that occurred under hyperbaric conditions without being triggered by defibrillation itself. To the best of our knowledge, there have been no published reports of any adverse events, regardless of severity, directly resulting from defibrillation under these conditions. Furthermore, much of the literature is based on older publications, the associated risks are often reiterated anecdotally, which may lead to an overstatement of its practical significance. Since then, advancements in technology, such as introduction of biphasic defibrillators, enhanced monitoring of oxygen concentrations, and use of adhesive pads may have contributed to risk reduction. These improvements call into question the accuracy of current risk assessments and suggest that comprehensive, updated studies are warranted to better evaluate risk management.

SAFETY PRECAUTIONS AND RECOMMENDATIONS FOR PERFORMING HYPERBARIC DEFIBRILLATION

Monitoring heart rhythm and detecting the necessity of defibrillation during HBOT is feasible in both chamber types.[3,23,40] As described above, they differ fundamentally in the way HBOT is applied.[23] Thus, recommendations must be considered separately.

Defibrillation inside monoplace chambers is strictly contraindicated. The patient must be evacuated after decompression first.[7,27,28,30–32,34–37,39–44] Emergency decompression can be performed within approximately one minute,[27,30,32,41,43] allowing the patient to be removed within 90 seconds.[43] Holcomb et al., recommend a rapid yet controlled decompression within two to four minutes, as the patient is likely to be sufficiently oxygenated, thus preventing potential complications.[28] It is worth considering whether the risk of barotrauma truly justifies delaying emergency decompression. Given the time-critical nature of cardiac arrest, the fastest possible decompression appears to be the more appropriate course of action. Safety precautions also include reducing 100% oxygen to normal air during decompression, if impossible, then at least 40 seconds should elapse before defibrillating so that the oxygen can dissipate.[27,42] Tests show that oxygen pouring out of the recently decompressed chamber dissipates within 30 to 40 seconds.[30,39,40] Removing the patient completely and maintain a distance[28,39–41] of six to eight feet from the recently decompressed chamber is a potential safety strategy.[37] The patient's oxygen saturated clothing should be removed beforehand.[27,39–42] All these measures aim to reduce the risk of fire. After evacuation, shocks may be delivered with recommended energy, as advised by the European Resuscitation Council.[46]

In multiplace chambers, some state that decompression must be performed beforehand.[2,3,7,9,18,21,25,29,37,38] Emergency decompression may take several minutes, as it must also align with decompression obligations of the personnel.[6,7,18,21,22,27,30,36,37] This is crucial to avoid putting them at risk, for example, from possible decompression sickness.[3,18,25,26,36–38] Muth recommends slow decompression while rescuers breathe 100% oxygen from 1.9 atmospheres absolute (atm abs) until normobaric.[18,36,37] This is supported by others,[7] as, depending on the indication (decompression sickness, arterial gas embolism), emergency decompression could potentially aggravate the cause of cardiac arrest.[9] In some clinical scenarios, such as extended recompression protocols, rapid emergency decompression is contraindicated due to the tender having a decompression obligation,[7,21] for example while using the extended US Navy Treatment Table 6. In these cases, in-chamber defibrillation might be indicated, with the potential delay in decompression carefully balanced against the hazards of performing hyperbaric defibrillation. This reinforces the necessity of defibrillation during HBOT in certain situations. Another option is evacuation of the patient through the patient lock, providing care outside, thus ensuring that staff and other patients continue their regular decompression scheme.[21]

Twenty-five years ago, Pitkin attempted to clarify this issue within his review on defibrillation in hyperbaric chambers.[9] He concluded that defibrillation can be performed during HBOT, but some safety issues remain. The potential benefits must be carefully weighed against the risks. Drug therapy for arrhythmias could be considered in special circumstances. Pitkin recommended emergency decompression and normobaric defibrillation if cardiac arrest occurred.[9]

Dieterich et al.,[6] developed an algorithm for shockable cardiac arrest during HBOT by implementing resuscitation training at their center considering that defibrillation is associated with a certain risk of fire and explosion. A battery-operated, portable defibrillator approved for hyperbaric use is stored outside. Using an emergency lock, the first shock may be delivered after just one to two minutes. The authors recommended delivery of the first shock with a reduced energy of 150 joules and also consider delivering a precordial thump if cardiac arrest has been observed and it does not delay defibrillation.[6]

In order to defibrillate despite the risks in multiplace chambers, strict safety precautions have to be obeyed.[2,6,7,9,12,20,22,23,26–28,30–35,42,44] These include maintaining chamber oxygen concentration < 21.5%, reducing risk of flammability and defibrillator storage and operation outside the chamber. Due to lack of data, no conclusive statement can yet be made about the use of battery-operated portable defibrillators. Use large adhesive pads and remove all flammable materials in the vicinity.[7,9,12,20,22,28,31–35,44] If no pads are used, gel should be applied to reduce impedance.[20,31,32,35,44] Maintain sufficient distance from the victim in order to reduce risk of shock transmission.[12] It should be noted that hyperbaric chambers are not ideal for defibrillation

because of their confined design and the possibility of shocking others. Appropriate measures include adequate grounding, use of insulating footwear, adhesive pads and biphasic current requiring less energy.[9,12] The majority of aforementioned measures were also recommended in Schmitz et al.'s review on cardiopulmonary resuscitation during HBOT.[12]

PATIENT OUTCOMES

It is hypothesised that hyperoxia during HBOT could prevent tissue hypoxia and thus have a positive effect on survival due to prolonging tolerance of cardiac arrest.[2,7,9,25,28–32,39–41] So far, there is a lack of sufficient data for this physiologically plausible construct.[21,25] These considerations may also not apply during oxygen breaks.[9,50] Moreover, if cardiac arrest were to occur during HBOT, it could nevertheless indicate presence of myocardial hypoxia despite general hyperoxia. In this situation, standard resuscitation protocols should be promptly applied, with immediate defibrillation considered if indicated and deemed safe.

In our scoping review, we identified a reported survival rate of 80% in cases where defibrillation or cardioversion was performed during HBOT, with no adverse effects mentioned – an outcome that appears promising. However, it is important to note that this is based on five patient cases, making any meaningful statistical analysis impossible. Additionally, there was no information provided on long-term outcomes, which limits the ability to draw definitive conclusions about the overall effectiveness and safety of defibrillation in this setting.[19,20,24,40] The risk of delayed defibrillation due to prior decompression must always be weighed against the risk of performing defibrillation during HBOT, as both can significantly impact patient outcomes. Up to now, the superiority of immediate defibrillation during HBOT compared to chest compression with rapid decompression and subsequent normobaric defibrillation has not yet been proven.[3]

LIMITATIONS

The limited evidence available may pose challenges to the robustness of this scoping review. This could be further compounded by restricting the selection of articles to those in English and German. It is important to acknowledge potential for publication bias regarding reported cases. This may result in an underrepresentation of actual patient cases in the literature. Addressing this issue in future research is essential to identify and account for the number of unreported cases, thereby providing a more accurate understanding of the clinical landscape. In a world where resuscitation algorithms have been developed to manage emergencies in extreme environments (such as space), the establishment of dedicated HBOT guidelines is equally justified and essential. Such guidelines would ensure optimised patient care, even in these highly specialised and challenging settings.

Conclusions

Defibrillation during HBOT remains an exceptionally rare, but potentially life-saving procedure, albeit one that might carry risk for chamber personnel and fellow patients. Expert opinions diverge, underscoring that any decision must be made on a case-by-case basis, with appreciation of local chamber characteristics and available safety measures. Regarding monoplace chambers there is strong consensus that defibrillation is strictly contraindicated. In multiplace chambers the benefit must always be weighed against the risk and the decision should ideally be made with consent of all those involved. Under stringent safety protocols and careful risk assessment, defibrillation may be performed safely. At present, given the uncertainty regarding whether the risk of severe complications is overestimated, it may be advisable to adopt a careful approach and consider in-chamber defibrillation only as a last-resort, e.g., when emergency decompression is unfeasible. Until the evidence base matures to support a more definitive recommendation, caution is advised. Future studies should incorporate additional endpoints, such as complications, patient mortality, one-month survival and neurological outcome. Further research and standardised guidelines are essential to show whether immediate defibrillation provides a benefit in survival and overall outcome compared to emergency decompression and normobaric defibrillation and to enhance safety and efficacy in these critical situations.

References

1 Huang E, editor. UHMS Hyperbaric Medicine Indications Manual, 15th ed. West Palm Beach (FL): Best Publishing; 2024.

2 Millar IL. Hyperbaric intensive care technology and equipment. Diving Hyperb Med. 2015;45:50–6. PMID: 25964040. [cited 2025 Aug 1]. Available from: https://dhmjournal.com/images/IndividArticles/45March/Millar_dhm.45.1.50-56.pdf.

3 Mathieu D, Ratzenhofer-Komenda B, Kot J. Hyperbaric oxygen therapy for intensive care patients: position statement by the European Committee for Hyperbaric Medicine. Diving Hyperb Med. 2015;45:42–6. PMID: 25964038. [cited 2025 Aug 1]. Available from: https://dhmjournal.com/images/IndividArticles/45March/Mathieu_dhm.45.1.42-46.pdf.

4 Gu W, Li CS. What is more important: defibrillation or compression? J Thorac Dis. 2016;8(8):E778–E80. doi: 10.21037/jtd.2016.05.72. PMID: 27622816. PMCID: PMC4999679.

5 Callans DJ. Out-of-hospital cardiac arrest – the solution is shocking. N Engl J Med. 2004;351:632–4. doi: 10.1056/NEJMp048174. PMID: 15306663.

6 Dieterich F, Kanstinger A, Erdmann M, Knebel J, Ott B, Schöppenthau H. [Implementation of regularly performed resuscitation training at a hyperbaric treatment center]. Anaesthesist. 2016;65:203–11. doi: 10.1007/s00101-016-0138-7. PMID: 26886384. German.

7 Kot J. Medical devices and procedures in the hyperbaric chamber. Diving Hyperb Med. 2014;44:223–7. PMID: 25596835. [cited 2025 Aug 1]. Available from: https://dhmjournal.com/images/IndividArticles/44Dec/Kot_dhm.44.4.223-227.pdf.

8 Helix Well Ops. Report on tests of Zoll automatic external defibrillator function in hyperbaric heliox conditions. [Internet]. 2014. [cited 2024 Aug 3]. Available from: https://www.dmac-diving.org/guidance/Helix-defib-report.pdf.

9 Pitkin A. Defibrillation in hyperbaric chambers: a review. J R Nav Med Serv. 1999;85:150–7. PMID: 10707456.

10 Lott C, Truhlář A, Alfonzo A, Barelli A, González-Salvado V, Hinkelbein J et al. European Resuscitation Council Guidelines 2021: Cardiac arrest in special circumstances. Resuscitation. 2021;161:152–219. doi: 10.1016/j.resuscitation.2021.02.011. PMID: 33773826.

11 Schmitz J, Kerkhoff S, Braunecker S, Warnecke T, Hinkelbein J. Kardiopulmonale Reanimation im Weltall: Cardiopulmonary resuscitation in space. Flug u Reisemed. 2018;25(04):162–6. doi: 10.1055/a-0655-1579.

12 Schmitz J, Liebold F, Hinkelbein J, Nöhl S, Thal SC, Sellmann T. Cardiopulmonary resuscitation during hyperbaric oxygen therapy: a comprehensive review and recommendations for practice. Scand J Trauma Resusc Emerg Med. 2023;31(1):57. doi: 10.1186/s13049-023-01103-y. PMID: 37872558. PMCID: PMC10658797.

13 Laden G, Mathew B, Ananthasayanam A. Time to shock people. Diving Hyperb Med. 2024;54:73–4. doi: 10.28920/dhm54.1.73-74. PMID: 38507914. PMCID: PMC11227958.

14 Tabner A, Johnson G, Bryson P. Response to Laden et al. Diving Hyperb Med. 2024;54:74–5. doi: 10.28920/dhm54.1.74-75. PMID: 38507915. PMCID: PMC11227962.

15 Johnson G, Tabner A, Tilbury N, Wesson A, Hughes GD, Elder R, et al. Development of an algorithm to guide management of cardiorespiratory arrest in a diving bell. Resusc Plus. 2024;19:100724. doi: 10.1016/j.resplu.2024.100724. PMID: 39100390. PMCID: PMC11295632.

16 Johnson G, Bryson P, Tilbury N, McGregor B, Wesson A, Hughes GD, et al. Delivering manual cardiopulmonary resuscitation (CPR) in a diving bell: an analysis of head-to-chest and knee-to-chest compression techniques. Diving Hyperb Med. 2023;53:172–80. doi: 10.28920/dhm53.3.172-180. PMID: 37718290. PMCID: PMC10597601.

17 Tricco AC, Lillie E, Zarin W, O'Brien KK, Colquhoun H, Levac D, et al. PRISMA extension for scoping reviews (PRISMA-ScR): Checklist and explanation. Ann Intern Med. 2018;169:467–73. doi: 10.7326/M18-0850. PMID: 30178033.

18 Muth CM, Radermacher P. Hyperbaric emergencies and decompression illness. Réanimation. 2015;24:551–6. doi: 10.1007/s13546-015-1091-1.

19 Murphy DG, Sloan EP, Hart RG, Narasimhan K, Barreca RS. Tension pneumothorax associated with hyperbaric oxygen therapy. Am J Emerg Med. 1991;9:176–9. doi: 10.1016/0735-6757(91)90186-N. PMID: 1994949.

20 Moon RE, Hart BB. Operational use and patient monitoring in a multiplace hyperbaric chamber. Respir Care Clin N Am. 1999;5:21–49. PMID: 10205812.

21 Wright KT, Praske SP, Bhatt NA, Magalhaes RM, Quast TM. Treatment of cardiac arrest in the hyperbaric environment: key steps on the sequence of care-case reports. Undersea Hyperb Med. 2016;43:71–8. PMID: 27000016.

22 Paganini M, Mormando G, Savino S, Garetto G, Tiozzo G, Camporesi EM, et al. Emergency medicine cases in underwater and hyperbaric environments: The use of *in situ* simulation as a learning technique. Front Physiol. 2021;12:666503. doi: 10.3389/fphys.2021.666503. PMID: 34093229. PMCID: PMC8176206.

23 Jain KK. Hyperbaric chambers: Equipment, technique, and safety. Textbook of hyperbaric medicine. Cham: Springer International Publishing; 2017. p. 79–84. doi: 10.1007/978-3-319-47140-2.

24 Wolf HK, Moon RE, Mitchell PR, Burger PC. Barotrauma and air embolism in hyperbaric oxygen therapy. Am J Forensic Med Pathol. 1990;11:149–53. doi: 10.1097/00000433-199006000-00009. PMID: 2343842.

25 Wiese S, Beckers S, Siekmann U, Baltus T, Rossaint R, Schröder S. [Hyperbaric oxygenation: characteristics of intensive care and emergency therapy]. Anaesthesist. 2006;55:693–705. doi: 10.1007/s00101-006-1021-8. PMID: 16775732.

26 Lind F. A pro/con review comparing the use of mono- and multiplace hyperbaric chambers for critical care. Diving Hyperb Med. 2015;45:56–60. PMID: 25964041. [cited 2025 Aug 1]. Available from: https://dhmjournal.com/images/IndividArticles/45March/Lind_dhm.45.1.56-60.pdf.

27 Weaver LK. Hyperbaric oxygen in the critically ill. Crit Care Med. 2011;39:1784–91. doi: 10.1097/CCM.0b013e31821858d1. PMID: 21460713.

28 Holcomb JR, Matos-Navarro AY, Goldmann RW. Critical care in the hyperbaric chamber. In: Davis JC, Hunt TK, editors. Problem wounds: the role of oxygen. New York: Elsevier; 1988. p. 187–209.

29 Kemmer A, Muth CM, Mathieu D. Patient management. In: Mathieu D, editor. Handbook on hyperbaric medicine. Dordrecht, The Netherlands: Springer; 2006. p. 651–69.

30 Kindwall EP. Management of complications in hyperbaric treatment. In: Kindwall EP, Whelan HT, editors. Hyperbaric medicine practice. Flagstaff (AZ): Best Publishing Co; 2004. p. 365–76.

31 Kot J. Medical equipment for multiplace hyperbaric chambers. Part 1: devices for monitoring and cardiac support. Eur J Underw Hyperb Med. 2005;6(4):115–20.

32 Kot J, Houman R, Müller P. Hyperbaric chamber and equipment. In: Mathieu D, editor. Handbook on hyperbaric medicine. Dordrecht, The Netherlands: Springer; 2006. p. 611–36.

33 Longoni C, Marchesi G. Adapting the hyperbaric chamber to the health care environment: history and future trends. In: Oriani G, Marroni A, Wattel F, editors. Handbook on hyperbaric medicine. Milano: Springer Milan; 1996. p. 741–64. doi: 10.1007/978-88-470-2198-3_27.

34 Martindale LG, Milligan M, Fries P. Test of an R-2 defibrillator adaptor in a hyperbaric chamber. J Hyperb Med. 1987;2:15–25.

35 Moon RE, Camporesi EM. Clinical care in extreme environments: at high and low pressure and in space. Miller's Anesthesia. Elsevier; 2015. p. 2674–704. doi: 10.1016/B978-0-443-06959-8.00080-7.

36 Muth CM. Intensivmedizin unter hyperbaren Bedingungen. In: Almeling M, Böhm F, Welslau W, editors. Handbuch Tauch- und Hyperbarmedizin. Landsberg/Lech: Ecomed; 1998. p. 1–26.

37 Muth CM, Radermacher P, Shank ES. When HBO meets the ICU—intensive care patients in the hyperbaric environment. In: Bakker DJ, Cramer FS, editors. Hyperbaric surgery, perioperative care. Flagstaff (AZ): Best Publishing Co; 2002. p. 111–58.

38 Tetzlaff K, Shank ES, Muth CM. Evaluation and management of decompression illness—an intensivist's perspective. Intensive Care Med. 2003;29:2128–36. doi: 10.1007/s00134-003-1999-1. PMID: 14600806.

39 Weaver LK. Management of critically ill patients in the monoplace hyperbaric chamber. In: Kindwall EP, editor. Hyperbaric medicine practice. Flagstaff (AZ): Best Publishing Co; 1995. p. 173–246.
40 Weaver LK. Management of critically ill patients in the monoplace hyperbaric chamber. In: Kindwall EP, Whelan HT, editors. Hyperbaric medicine practice. Flagstaff (AZ): Best Publishing Co; 2004. p. 245–322.
41 Weaver LK. The treatment of critically ill patients with hyperbaric oxygen therapy. In: Brent J, Wallace KL, Burkhart KK, Phillips SD, Donovan JW, editors. Critical care toxicology: diagnosis and management of the critically poisoned patient. Philadelphia: Elsevier Mosby; 2005. p. 181–7.
42 Weaver LK. Critical care of patients needing hyperbaric oxygen. In: Neuman TS, Thom SR, editors. Physiology and medicine of hyperbaric oxygen therapy. Philadelphia: Saunders Elsevier; 2008. p. 117–29. doi: 10.1016/B978-1-4160-3406-3.X5001-X.
43 Weaver LK, Strauss MB. Monoplace hyperbaric chamber safety guidelines: report to the hyperbaric chamber safety committee of the Undersea and Hyperbaric Medical Society. Kensington, Maryland: Undersea and Hyperbaric Medical Society; 1997.
44 Ratzenhofer-Komenda B, Kemmer A. HBO in intensive care. Proceedings of the 7th European consensus conference on hyperbaric medicine. Lille: European Committee for Hyperbaric Medicine; 2004.
45 Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ. 2021;372:n71. doi: 10.1136/bmj.n71. PMID: 33782057. PMCID: PMC8005924.
46 Perkins GD, Gräsner JT, Semeraro F, Olasveengen T, Soar J, Lott C, et al. European Resuscitation Council Guidelines 2021: Executive summary. Resuscitation. 2021;161:1–60. doi: 10.1016/j.resuscitation.2021.02.003. PMID: 33773824.
47 Jacobs I, Sunde K, Deakin CD, Hazinski MF, Kerber RE, Koster RW, et al. Part 6: Defibrillation: 2010 international consensus on cardiopulmonary resuscitation and emergency cardiovascular care science with treatment recommendations. Circulation. 2010;122(16 Suppl 2):S325–37. doi: 10.1161/CIRCULATIONAHA.110.971010. PMID: 20956254.
48 Simini B. Milan fire fuels concerns over hyperbaric oxygen facilities. Lancet. 1997;350(9088):1375. doi: 10.1016/S0140-6736(05)65155-0.
49 Sheffield PJ, Desautels DA. Hyperbaric and hypobaric chamber fires: a 73-year analysis. Undersea Hyperb Med. 1997;24:153–64. PMID: 9308138.
50 Weaver LK, Churchill SK. Hypoxemia with air breathing periods in U.S. NAVY Treatment Table 6. Undersea Hyperb Med. 2006;33:11–5. PMID: 16602252.

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